National Library of Canada
Bibliothèque nationale du Canada

Canadian Theses Service
Service des thèses canadiennes

Ottawa, Canada
K1A 0N4

NOTICE

The quality of this microform is heavily dependent upon the quality of the original thesis submitted for microfilming. Every effort has been made to ensure the highest quality of reproduction possible.

If pages are missing, contact the university which granted the degree.

Some pages may have indistinct print especially if the original pages were typed with a poor typewriter ribbon or if the university sent us an inferior photocopy.

Reproduction in full or in part of this microform is governed by the Canadian Copyright Act, R.S.C. 1970, c. C-30, and subsequent amendments.

AVIS

La qualité de cette microforme dépend grandement de la qualité de la thèse soumise au microfilmage. Nous avons tout fait pour assurer une qualité supérieure de reproduction.

S'il manque des pages, veuillez communiquer avec l'université qui a conféré le grade.

La qualité d'impression de certaines pages peut laisser à désirer, surtout si les pages originales ont été dactylographiées à l'aide d'un ruban usé ou si l'université nous a fait parvenir une photocopie de qualité inférieure.

La reproduction, même partielle, de cette microforme est soumise à la Loi canadienne sur le droit d'auteur, SRC 1970, c. C-30, et ses amendements subséquents

NL-339 (r. 88/04) c

Canada

THE UNIVERSITY OF ALBERTA

Manipulation of Relief in a Thematic Mapper Scene of Mountainous Terrain in the Yukon

by

Allan H. Evans

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
AND RESEARCH IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF

Master of Science

Department of Geography

Edmonton, Alberta

Fall, 1990

National Library of Canada
Bibliothèque nationale du Canada

Canadian Theses Service
Service des thèses canadiennes

Ottawa, Canada
K1A 0N4

The author has granted an irrevocable non-exclusive licence allowing the National Library of Canada to reproduce, loan, distribute or sell copies of his/her thesis by any means and in any form or format, making this thesis available to interested persons.

L'auteur a accordé une licence irrévocable et non exclusive permettant à la Bibliothèque nationale du Canada de reproduire, prêter, distribuer ou vendre des copies de sa thèse de quelque manière et sous quelque forme que ce soit pour mettre des exemplaires de cette thèse à la disposition des personnes intéressées.

The author retains ownership of the copyright in his/her thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without his/her permission.

L'auteur conserve la propriété du droit d'auteur qui protège sa thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

ISBN 0-315-65077-X

THE UNIVERSITY OF ALBERTA

RELEASE FORM

NAME OF AUTHOR Allan H Evans

TITLE OF THESIS Manipulation of Relief in a Thematic Mapper Scene of Mountainous Terrain in the Yukon

DEGREE FOR WHICH THESIS WAS PRESENTED Master of Science

YEAR THIS DEGREE GRANTED 1990

Permission is hereby granted to **THE UNIVERSITY OF ALBERTA LIBRARY** to reproduce single copies of this thesis and to lend or sell such copies for private, scholarly or scientific purposes only.

The author reserves other publication rights, and neither the thesis nor extensive extracts from it may be printed or otherwise reproduced without the author's written permission

A Evans

1835 Cayuga Cres. N.W.
Calgary, Alberta
Canada, T2L ON7

DATED July 5 1990

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled **MANIPULATION OF RELIEF IN A THEMATIC MAPPER SCENE OF MOUNTAINOUS TERRAIN IN THE YUKON** submitted by Allan H. Evans in partial fulfilment of the requirements for the degree of Master of Science.

Supervisor

Date July 5 1990

ABSTRACT

The direction of lighting in an image is a key component in interpreting the topology of the landscape. Altering the apparent direction of illumination in a satellite scene can be accomplished by imposing an artificial topographic lighting effect through intensity inversion, spatial filtering, or manipulation with an illumination model. The direct manipulation of individual satellite bands results in blue monochromatic regions in shadowed areas due to Rayleigh scattering and path radiance. Inverting the grey scale for the individual bands of a composite results in the formation of a colour-negative. Conversion of the visible bands into hue-saturation-intensity colour-space allows for the separate processing of chromaticity (hue and saturation) and intensity components. The separate components can then be manipulated to reduce the shadow-effect while retaining a correct colour rendition. The image can then be converted back into red-green-blue colour-space resulting in a topologically correct cartographic model of the landscape, illuminated from the desired orientation.

ACKNOWLEDGEMENTS

I would like to thank Ron Eyton for all the help and direction that he has given me. His ability to show that the simple, straight-forward method is usually the best will remain with me forever. It was one of Ron's courses that introduced me to the entire field of digital cartography and remote sensing; I hope that others can be as fortunate.

My parents, A. Harold Evans and Frances M. Evans, deserve an enormous amount of credit for their help and perseverance over the many years. Even in the darkest moments of a Dean's vacation they assured me of my eventual success.

I would also like to thank Doris Sharp, without whom life would be lonely and dull; Dan Hemenway for exorcising demons from the various computer systems; Bob Skoye for the many evenings in Dewey's; various other geographers for their comments and hockey hints; Paul G. Rivard for his self-assured ability to do anything; Greg Wells for his friendship; and assorted fraternal brothers of Delta Upsilon for their support in what was once a lonely spot away from home.

TABLE OF CONTENTS

I INTRODUCTION 1

Background 2

II DATA 9

Thematic Mapper Scene 9

Digital Elevation Model 12

Illumination Model 12

III HUE-SATURATION-INTENSITY COLOUR-SPACE 15

Hue-Saturation-Value Hexcone 18

Pre-Processing 18

IV MANIPULATION OF THE APPARENT DIRECTION OF ILLUMINATION 30

Direct Manipulation using an Illumination Model 30

Manipulation using LUT inversion 35

High-Frequency Filtering 38

Medium and High-Frequency Filtering 44

V SUMMARY AND CONCLUSIONS 52

LIST OF TABLES

Table 1. Spectral Bandwidths Recorded by the Thematic Mapper Sensor Aboard the Landsat Satellite Platform 11

LIST OF FIGURES

Figure 1. Study area (subset) in the Wheaton district of the southern Yukon (von Gaza, 1989). 10

Figure 2. RGB colour cube with colour vector superimposed. 16

Figure 3. Hexcone plane as viewed down the achromatic axis toward the origin with colour vector superimposed. 17

Figure 4. The illumination model is scaled using extremes obtained from the value image to produce correction values for each pixel. 31

LIST OF PLATES

Plate 1. (a) Spheroids shaded from the bottom appear convex, while those shaded from above appear concave. (b) The illusion is caused by gradational shading, and not the polarity (Ramachandran, 1988). 3

Plate 2. Hollow casts of faces lit from above appear convex due to familiarity, the contextual cues override the assumption of overhead illumination (Ramachandran, 1988). 5

Plate 3. Illumination model with azimuth of light source at 333° and at an elevation of 34°. 14

Plate 4. Colour composite of bands 1, 2 and 3 contrasted stretched with saturation (solar azimuth = 153°; solar elevation = 34°). 20

Plate 5. Hue image generated from bands 1, 2, and 3 with approximate colour assigned from a LUT. 22

Plate 6. Hue image generated from bands 1, 2 and 3 and processed with a 5X5 median boxcar filter, approximate colour assigned from a LUT. 23

Plate 7. Saturation image generated from bands 1, 2 and 3. 24

Plate 8. Saturation image generated from bands 1, 2 and 3 and thresholded (DN 180-255 set to 0). 27

Plate 9. Thresholded saturation image processed with a 9x9 averaging boxcar filter. 28

Plate 10. Value image generated from bands 1,2 and 3. 29

Plate 11. Value image generated from bands 1, 2 and 3 and processed using intensity conversions calculated from the illumination model. 33

Plate 12. Colour composite of direct manipulation scene, recombined from processed chromaticity and value components. 34

Plate 13. Inverted value image with snow areas thresholded to blend in with surrounding cover (DN=0 set to 100). 36

Plate 14. Colour composite of LUT inversion scene, recombined from processed chromaticity and value components. 37

Plate 15. Value image processed with a 9x9 averaging boxcar filter. 39

Plate 16. High-Frequency residual image from the subtraction of the averaged value image from the unprocessed value image. 40

Plate 17. Inverted high-frequency residual image from the subtraction of the averaged value image from the unprocessed value image. 41

Plate 18. Inverted high-frequency residual image added to an illumination model. 42

Plate 19. Colour composite of high-frequency addition scene, recombined from processed chromaticity and value components. 43

Plate 20. Medium-frequency residual image from the subtraction of the illumination model (light azimuth=153°) from the unprocessed value image. 45

Plate 21. Medium-frequency residual image added to an illumination model (light azimuth=333°). 47

Plate 22. Colour composite of medium and high-frequency addition scene, recombined from processed chromaticity and value components. 48

Plate 23. Inverted medium and high-frequency residual image from the subtraction of the illumination model from the unprocessed value image. 49

Plate 24. Inverted medium and high-frequency residual image added to an illumination model. 50

Plate 25. Colour composite of inverted medium and high-frequency addition scene, recombined from processed chromaticity and value components. 51

I INTRODUCTION

The impression of relief obtained in a satellite scene results from cues the human brain takes from the differential reflectance levels in an image that are caused by the topographic lighting effect and shadows, combined with the reflectance properties of surface features and the spatial context in which the scene is viewed. Thematic Mapper scenes in the northern hemisphere are illuminated from the southeast; in rugged terrain this often results in the appearance of inverted relief which hinders scene understanding. Re-orientating the apparent direction of illumination to the northwest ensures that most people will perceive the topology of the landscape correctly when the image is oriented with north towards the top.

This thesis examines techniques with which the apparent direction of illumination in a nadir-pointing satellite image can be altered by manipulating the scene intensity or radiance. In areas of moderate relief the topographic lighting effect is subtle, and the perception of the landscape is not generally hindered by the southeast orientation of illumination. In rugged terrain interpretation is complicated by shadowed areas that obscure the landscape and by greater contrast differences between sun-facing and sun-opposing slopes that amplify the tendency to see the topography as inverted. Several techniques that address these problems have been developed in this research and include: 1. using an artificial illumination model calculated

from a digital elevation model, 2. intensity inversion, and 3. spatial filtering. The resulting images preserve the spectral and contextual integrity of the scene, while presenting a correct topographic perspective.

Background

The key element in recognizing three-dimensional topographic expression in a satellite scene is the shading effect resulting from differential lighting of the landscape. This topographic lighting effect is formally defined as the variation in response from inclined surfaces compared to response from a horizontal surface as a function of the orientation of the surface relative to the light source and sensor position (Holben and Justice 1981, Justice *et al.* 1981). In an image produced with a nadir-pointing sensor, this effect gives the appearance of hill-shading with respect to a light source located to one side of the image; this technique has long been employed by cartographers to simulate relief. Humans prefer illumination directly above their field of vision and assume that to be the case if spatial and contextual cues are not obvious.

This location preference for the source of illumination can be demonstrated using shaded shapes (Ramachandran, 1988). Shaded 'spheres' appear convex when shaded as if lit from above, and concave when shaded as if lit from below (Plate 1). If the same spheres are viewed from the side however, their orientation becomes ambiguous and

Copyright permission for this photographic plate was not obtained. The plate has been omitted.

Plate 1. (a) Spheroids shaded from the bottom appear convex, while those shaded from above appear concave. (b) The illusion is caused by gradational shading, and not the polarity (Ramachandran, 1988).

their shape will appear either convex or concave. The topographic lighting effect causes similar perceptual ambiguities when the illumination source is near the bottom of the image; however contextual cues provided from the spatial configuration of the image tend to compensate as the light source approaches the 'visual horizon' (90 or 270 degrees). Von Gaza (1989) noted that experience interpreting satellite images or similar imagery (eg. air photographs) reduced the reliance on lighting orientation substantially. To ensure that everyone can visualize the topology of the landscape correctly and retain the standard map orientation the direction of lighting must be moved. This can be accomplished by manipulating the topographic lighting effect or by imposing an artificial effect on the image. As with shading, the topographic lighting effect results in variation in the intensity of reflected light and is independent from the spectral composition of the light. Any manipulation of the effect therefore must affect only the intensity component of the image.

Texture, albedo, and spatial context are used as cues to assist, and occasionally override relief interpretation from lighting cues. Texture and albedo are functions of the reflectance and scattering characteristics of the surface cover type, while spatial context depends on the scale of the image and the type of landscape being examined. The faces in Plate 2 are hollow casts of a face lit from above, however because humans are conditioned to expect a face to be convex, they appear to be normal faces lit from below. Thus, although shading is the

Copyright permission for this photographic plate was not obtained. The plate has been omitted.

Plate 2. Hollow casts of faces lit from above appear convex due to familiarity, the contextual cues override the assumption of overhead illumination (Ramachandran, 1988).

dominant cue used to determine relief, it is often aided or confused by an individuals' capability to infer an interpretation of scene components from a familiar setting. Cues derived from drainage and vegetation patterns assist in the interpretation of a landscape, especially for trained individuals. If the spectral balance, spatial orientation, and the lighting source complement the perception of the correct topology, the ability of individuals to comprehend the scene is enhanced.

Shadow is the result of the obstruction of light by the terrain and is exacerbated by extreme relief and low sun angle. This hinders the perception of three dimensional space and the recognition of cover type characteristics, and thus is undesirable in image products (Gilman, 1981). Shadowed areas are not illuminated directly, but do receive indirect illumination from Rayleigh scattering in the atmosphere and light reflected from surrounding features (Kimes *et al*, 1981). The spectral composition of this secondary light is dependent on the scattering quality of the atmosphere and the absorption characteristics of the surrounding terrain, and thus is spectrally different from direct solar illumination. The short wavelength scattered light illuminates some surficial features enough to be resolved, albeit somewhat monochromatically. In the red or longer wavelength images there is essentially no illumination visible within shadows. The digital number (DN) associated with a given pixel in the image is also affected by light scattered directly from within the atmosphere into the receiving apparatus (path radiance). Due to the low levels of illumination within

shadows, path radiance can be a substantial part of the recorded digital value.

The topographic lighting effect is independent of the spectral component of the scene, and thus can be manipulated directly using either multiplicative corrections calculated from ancillary data, or by the ratioing of spectral channels. The recorded DN's in shadowed regions are biased towards the blue channel and any direct increase of intensity in those regions results in an almost monochromatic response within those areas. Large blue non-water tracts within the image would be a source of confusion due to their 'un-natural' appearance. This problem can be overcome by isolating the colour from the intensity in an alternate colour-space. Conversion from red-green-blue colour-space into hue-saturation-intensity colour-space enables colour (hue) and purity of colour (saturation) to be processed independently from the intensity component; the combination of hue and saturation is known as chromaticity. An artificial topographic lighting effect can then be imposed on the intensity component through removal or processing of the existing effect, while thresholding and filtering can be used to reduce the saturation of the shadowed areas. The scene can then be converted back into normal colour-space with the apparent direction of illumination altered.

Four methods of intensity manipulation are demonstrated in this research, three methods that require ancillary data in the form of an illumination model and one method that stands alone. The first method

uses an illumination model to calculate a multiplicative intensity correction which is used to alter the intensity component within the image. The second method uses inversion of the intensity to flip the direction of the apparent illumination source. The third and fourth methods use filters to remove information from the original intensity image, which is then added to an illumination model and rescaled for viewing. All four use enhancements of the hue and saturation components which are then recombined with the altered intensity images and converted back into red-green-blue colour-space. The resulting images enhance different aspects of the terrain while presenting the scene in such a manner that the correct topological context of the landscape is readily interpreted using normal colours.

II DATA

The study area is located in the Wheaton District of the Yukon Territory just north of the British Columbia border on the eastern edge of the Coast Mountains (Figure 1). The image covers an approximately 50 km by 50 km area of rugged, mountainous terrain that comprises more than one fifth of the National Topographic Series (NTS) 1:250,000 map 105D. The landscape ranges from 650 m asl to over 2500 m asl (Crooks, 1989). Coniferous forests cover the valleys up to an elevation of 1300 m, above which lie alpine vegetation and bare rock (von Gaza, 1989).

Thematic Mapper Scene

The digital image dataset was acquired by the Thematic Mapper (TM) on September 6, 1986 at approximately 9:30 am from the Landsat 4 satellite. The dataset consists of three visible channels, three near-visible infrared channels, and one thermal channel (Table 1). At the time of acquisition the sun was at an elevation of 34 degrees from the horizon and at an azimuth of 153 degrees from north. A subset was extracted from the scene, geometrically corrected and registered to a Universal Transverse Mercator projection, and resampled to 100 m grid cells. The scene was then registered to NTS map 105D to facilitate construction of a digital elevation model; overall registration accuracy was approximately 33 m or one-third of a pixel (Crooks, 1989).

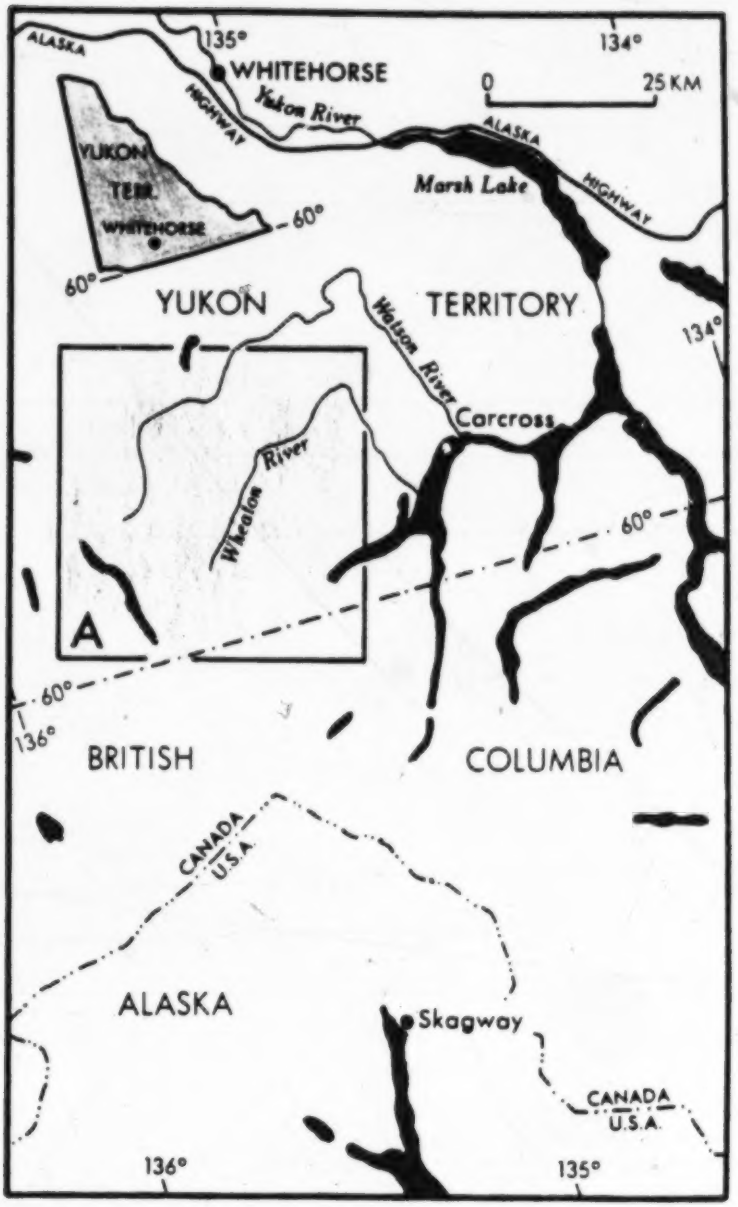


Figure 1. Study area (subset) in the Wheaton district of the southern Yukon (von Gaza, 1989). (unpublished material)

Table 1. Spectral Bandwidths Recorded by the Thematic Mapper Sensor Aboard the Landsat Satellite Platform

TM Band	Spectral Label	Spectral Range (nm)
1	visible (blue)	450-520
2	visible (green)	520-600
3	visible (red)	630-670
4	near-visible IR	760-900
5	near-visible IR	1550-1750
6	thermal	10400-12500
7	near-visible IR	2080-2350

Digital Elevation Model

The region covered by the TM scene was digitized from the 1:250,000 NTS map using point mode sampling and surfaced using a multiquadric equation algorithm based on an analytical interpolation approach. Multiquadric surfacing was used because the equations were designed for topographic expression where the fitted surface must pass through all of the observation points exactly (Crooks, 1989). The resulting DEM was then smoothed using a low-pass boxcar filter to produce a 550 row by 594 column grid.

Illumination Model

An illumination model was needed to determine intensity corrections, filter low-frequency intensity patterns, and as a relative radiance model. The model was calculated using slope magnitude and slope azimuth datasets generated form a differential geometry program developed by Eyton (1989). The relative illumination intensity was then calculated from a standard cosine function assuming no shadows (after Civco, 1989) where:

φ	=	topographic aspect angle
φ_o	=	illumination source azimuth
θ	=	zenith angle of the surface normal
θ_o	=	illumination source zenith angle
Υ	=	cosine angle between the illumination source angle and the local surface normal (relative illumination)

$$\Upsilon = \cos\theta_o \cos\theta + \sin\theta_o \cos\theta \cos(\varphi - \varphi_o)$$

The resulting illumination model was then scaled into 1 byte (between 1 and 255) to facilitate display and to standardize the input for the intensity manipulation programs. The solar azimuth for the altered images was chosen to be exactly 180° from the original TM image dataset (333°) and at the same solar elevation 34° (Plate 3).

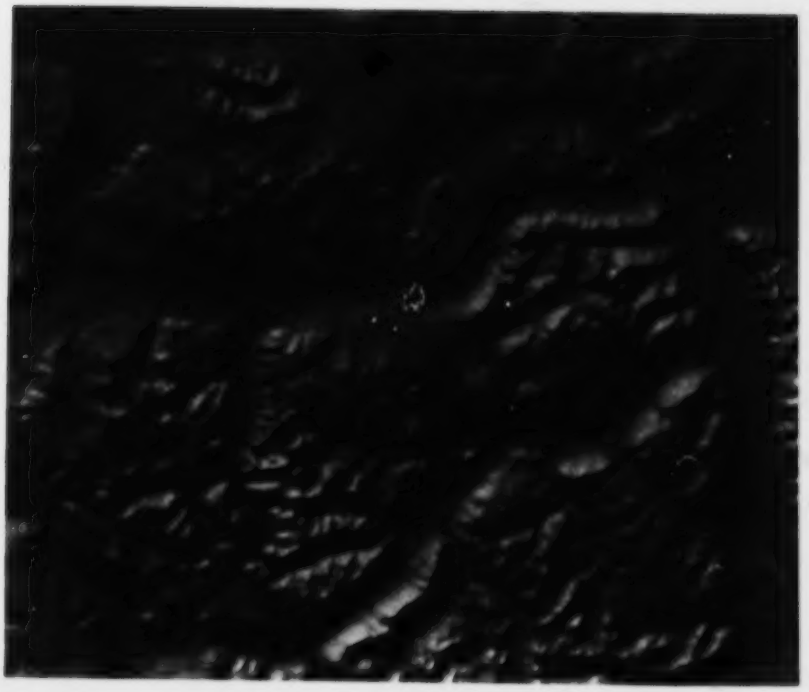


Plate 3. Illumination model with azimuth of light source at 333° and at an elevation of 34°.

III HUE-SATURATION-INTENSITY COLOUR-SPACE

The need to isolate the colour from the topographic and textural components can be accomplished by using an alternate colour-space. Colour can be represented as levels of red, green and blue (RGB), or alternatively as hue, saturation and intensity (HSI). The HSI conversion from RGB redefines the coordinate system in which the location of a pixel in colour-space is determined. The location of a pixel in HSI colour-space is represented by a vector from the origin in a colour cube (Figure 2). The intensity of light is the length along the achromatic axis (neutral: red=green=blue), on which there is no colour but a continuum of light intensity from black to white. The strength or purity of colour (saturation) is represented by the perpendicular distance from the vector to the achromatic axis. Hue is depicted by the clockwise angle from pure red looking down the achromatic axis. HSI is often employed in workstations that use colour, such as in some Tektronics systems, or as a representation scheme analogous to an artists' palette. HSI has also been the basis for an image processing technique used to expand the colour-space occupied by an RGB image in order to enhance small spectral differences (Gillespie *et al.* 1986). The techniques presented here use HSI to retain the original colour while manipulating the intensity component rather than being employed for spectral enhancement.

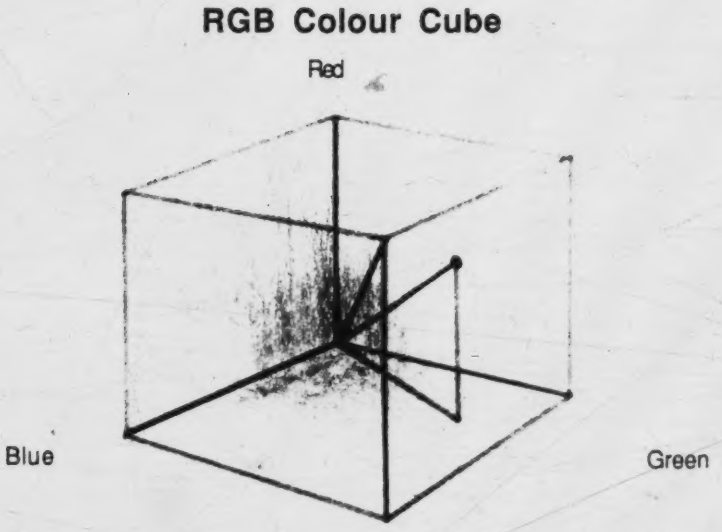
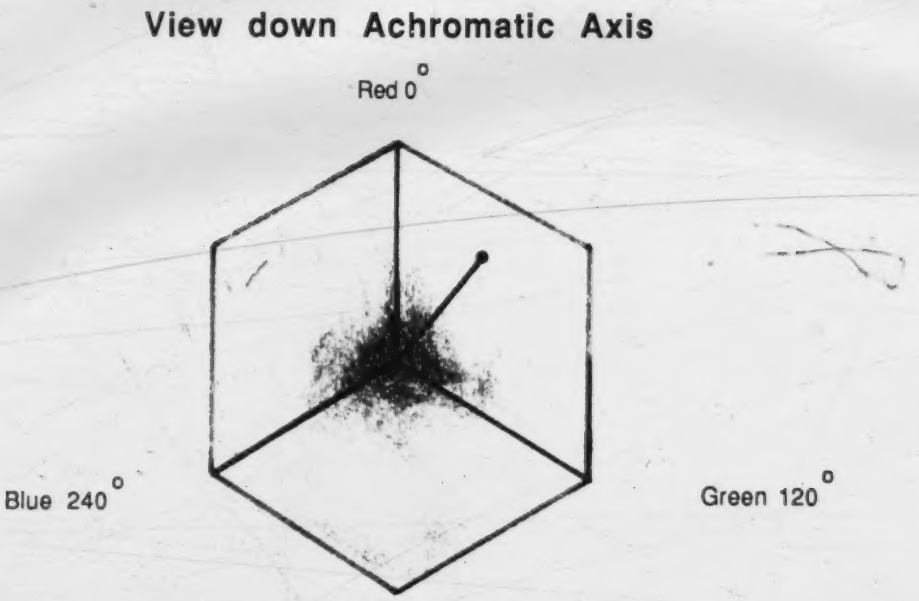


Figure 2. RGB colour cube with colour vector superimposed.



Hue: angle clockwise from red
Saturation: distance from achromatic axis
Intensity (Hexcone Approximation): series of planes from 0 to 255

Figure 3. Hexcone plane as viewed down the achromatic axis toward the origin with colour vector superimposed.

Hue-Saturation-Value Hexcone

Several methods that are less computationally rigorous have been developed to approximate the RGB to HSI conversion. The method employed in this research is known as the hexcone hue-saturation-value (HSV) model in which a series of planes (value) perpendicular to the achromatic axis represent intensity (Smith 1978, Rogers 1985). The series of planes from 0 to 255 form the hexcone (Figure 3). The interior points are those colours one would see looking at the colour cube along the achromatic axis in the direction from white to black. Although value in HSV and intensity in HSI are not the same, the quantitative difference between the two is mostly one of scale and is not important to this study. In order for the HSV images to be useful, several pre-processing steps must be taken to ensure that the HSV components represent the desired colour.

Pre-Processing

The digital number (DN) in a satellite image represents a combination of reflected radiation, light scattered in the atmosphere, and sensor gain. In order to retain the visible colour, and acquire as much information in shadowed areas as possible, only visible-light spectral bands were used in this research (Table 1). Direct conversion of these bands into HSV would result in blue predominating due to the Rayleigh scattering in the shorter wavelengths and additive path radiance. A common radiometric enhancement technique, contrast

stretching with saturation, was used to expand the contrast range of the image and normalize the grey-level distribution with respect to the other channels. The DNs for each band were clipped at the highest and lowest 2% of the digital range of the image and stretched between those DNs, with extreme values saturated at 0 (black, no intensity) and 255 (highest intensity). When combined into a normal RGB image a clear, high-contrast normal colour image results (Plate 4).

The red, green and blue spectral bands were then transformed into hue, saturation and value images. The hue image was rescaled from 0-360 to 0-255 for display purposes. The chromaticity components (hue and saturation) were processed to ensure that the visual characteristics of the end product were the best cartographic representation of the landscape while minimizing the anomalous blue regions caused by shadow. The actual enhancements were subjective, and allowed for considerable leeway in their generation.

The absorption characteristics of the surface, spectral composition of the illumination source, and addition from path radiance usually resulted in the dominance of one bandwidth for a given pixel. The hue image (Plate 5) represents the dominant colour recorded by the sensor as calculated from the three TM bands. The hue dataset was displayed as an image using a 'look-up-table' (LUT) to assign an approximation of colour; pure red and non-saturated regions (no dominant colour) are depicted as black. Mountainous areas in good to moderate light show dominance in longer wavelengths, while forested areas show dominance

Plate 4. Colour composite of bands 1, 2 and 3 contrasted stretched with saturation (solar azimuth = 153°; solar elevation = 34°).

in shorter blue and green wavelengths. Shadowed areas are illuminated by predominantly blue light due to the absence of longer wavelength illumination and the inclusion of path radiance. The images are noisy in shadowed areas, in the transition regions between different cover types, and along the edges of shadowed regions. The coarse resolution of the resampled image dataset (100 m) exacerbates the problem. The noise level was reduced by filtering primarily for aesthetic reasons. A median boxcar filter was employed to reduce the noise level by replacing the centre pixel value with the median of all values within the boxcar. The amount of generalization that occurred was a function of the size of the boxcar neighbourhood; a 3x3 filter did not reduce the noise level substantially in shadowed sections, while the 9x9 region over-generalized. A 5x5 boxcar filter was finally chosen because it fulfilled the noise-removal requirements without over-generalizing the image (Plate 6). The choice of filter size is subjective, and reducing or enlarging the boxcar will not substantially change the final processed RGB scene.

The degree to which a single bandwidth is dominant is measured by the saturation level. The saturation image (Plate 7) represents the purity of colour, or the perpendicular distance from the achromatic axis to the vector endpoint in the hexcone. Vegetated areas have low saturation, due to the absorption of most of the incoming radiation and reflection of light that is only slightly dominated by the green channel. Rock surfaces reflect back much of the incoming radiation, however they absorb proportionately more short-wavelength radiation than long-

Plate 5. Hue image generated from bands 1, 2, and 3 with approximate colour assigned from a LUT.

Plate 6. Hue image generated from bands 1, 2 and 3 and processed with a 5X5 median boxcar filter, approximate colour assigned from a LUT.

Plate 7. Saturation image generated from bands 1, 2 and 3.

wavelength radiation, resulting in moderate saturation values. The dominance of the blue bandwidth in shadowed areas ensures that saturation levels are extremely high. If the intensity of shadowed regions is merely increased to simulate an artificially greater reflectance they will appear blue. Reducing the saturation level within shadowed areas results in grey tones which detract less from the appearance of the mountainside and valleys than the large anomalous blue tracts of shadowed areas.

Reduction in saturation can be achieved because the digital value within shadowed areas is much greater than in the rest of the image, with the exception of some glacial lakes. The DN range 180-255 was set to zero (Plate 8) and the image was smoothed to reduce saturation variability (Plate 9). The amount of smoothing required depends on the amount of noise remaining within the shadowed areas after thresholding. Without filtering, lake and shadow areas would have regions of moderately high saturation (150-179) and no saturation (0). If recombined to an RGB image at this stage, the regions would have contained detracting blocky areas of blue colour and grey in the RGB scene. The smoothing operation used a conventional averaging boxcar filter; three neighbourhood sizes were tested: 3x3, 5x5, and 9x9. The largest shadowed region was greater than ten pixels across over much of its length and required a large boxcar to agglomerate the low and high ranges satisfactorily. Blockiness within lakes persisted when 3x3 and 5x5 neighbourhoods were used and when the 9x9 filter was

Plate 8. Saturation image generated from bands 1, 2 and 3 and thresholded (DN 180-255 set to 0).

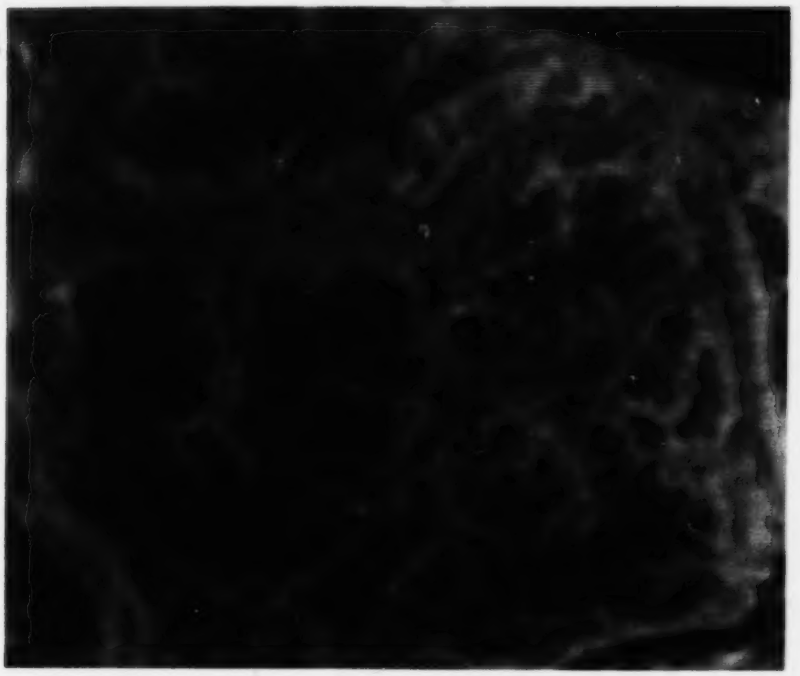


Plate 9. Thresholded saturation image processed with a 9x9 averaging boxcar filter.

employed the resulting image was blurred. The lack of definition in the blurred saturation image was found not to detract from the visual quality of the recombined RGB image because the topographic definition of the terrain is contained within the intensity image. The difference in colour along the boundary between cover types due to the blending of disparate saturation levels was essentially imperceptible, while the amount of blockiness within shadows and lakes was reduced considerably using a 9x9 boxcar.

The value image (Plate 10) represents the relative intensity of radiation recorded by the TM sensor in the visible channels. Regions that reflect much of the incoming radiation are very bright, while areas that absorb most of the energy are dark. Snow covered peaks are extremely bright and saturate within the image due to the almost total reflectance of incoming illumination. Mountain peaks in direct illumination have moderate intensity while forested areas are dark due to absorption. Shadowed areas are extremely dark, and reflect very little radiation due to low illumination levels. The topographic lighting effect is contained within the intensity component of the image, and thus intensity manipulation techniques were confined to the value image.

Plate 10. Value image generated from bands 1,2 and 3.

IV MANIPULATION OF THE APPARENT DIRECTION OF ILLUMINATION

Direct Manipulation using an Illumination Model

Direct manipulation of image intensity using an illumination model required that corrections for each pixel were calculated using the extremes derived from the value image. In order to shift the apparent direction of lighting from 153 degrees azimuth to 333 degrees, the manipulation must give the appearance of inverting the topographic lighting effect. The intensity of very dark facets with sun-opposing azimuths must be increased by an appropriate amount so as to appear as bright as sun-facing facets without saturating. The converse is true for areas of high intensity that must be darkened to the same level as sun-opposing facets in order for the topographic lighting effect to be inverted. The minimum DN which occurs on sun-opposing facets and the maximum DN which occurs on sun-facing facets in the value image were used to scale the illumination model to produce intensity correction values of sufficient magnitude to invert the topographic lighting effect (Figure 4). When the illumination model is at a minimum (DN=1) the intensity correction is equal to the ratio of the minimum value image level over the maximum value image level. The opposite is true when the model is at a maximum (DN=255) and the intensity correction is equal to the ratio of the maximum value image level over the minimum value image level. No change is required when the illumination model

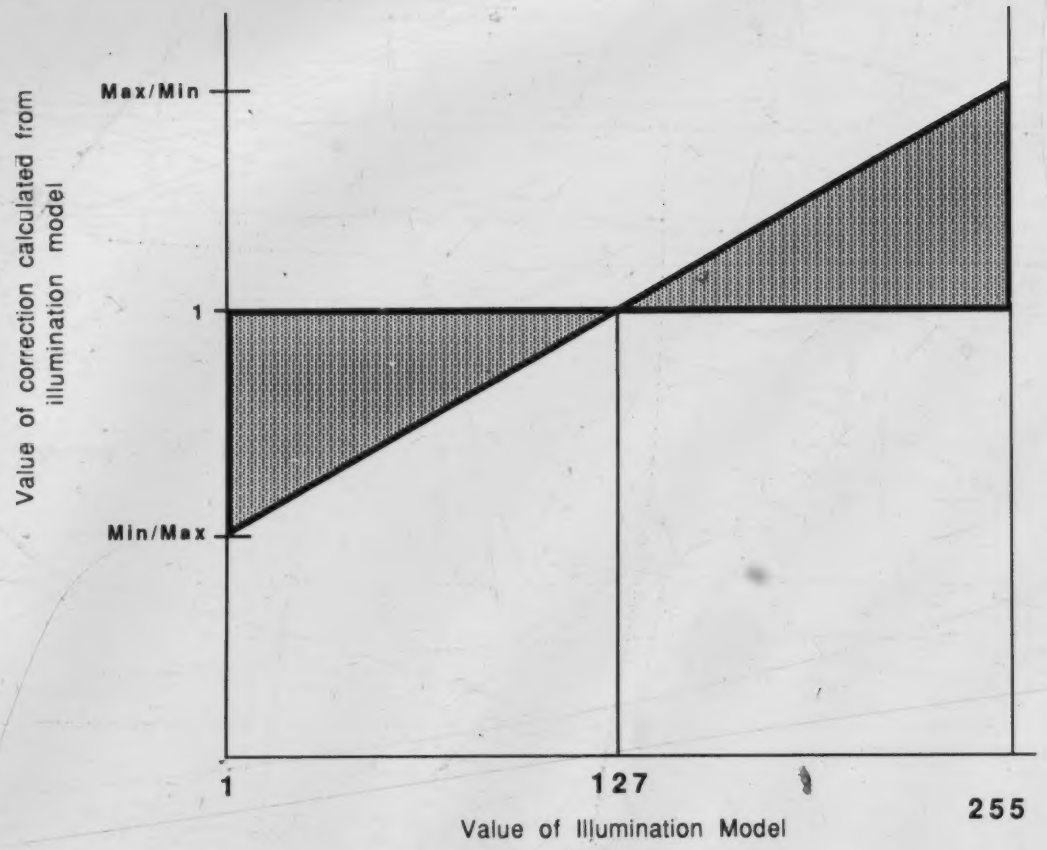


Figure 4. The illumination model is scaled using extremes obtained from the value image to produce correction values for each pixel.

DN equals 127 (middle value) because the azimuth angle for the source of illumination is the same in both the model and the value image. The DN's lower than 127 are stretched between the low ratio (minimum over maximum) and one, while DN's greater than 127 are stretched between one and the high ratio (maximum over minimum). The value image minimum and maximum are determined from a histogram of the image; anomalous outliers caused by extremely dark shadow or extremely bright snow cover are ignored.

The corrections were used to multiply the corresponding digital numbers in the image, which were then rescaled between 1 and 255. This technique could be applied to the original TM bands if very few shadowed areas existed; however due to the relatively low sun angle and rugged terrain the technique was applied to the intensity component only. The processed image (plate 11) contains the intensity information of the three visible TM bands with the altered topographic lighting effect. When the image was recombined with the processed chromaticity components (hue and saturation) the saturation level in shadows was reduced and the orientation of the apparent illumination source moved from the original 153 degrees azimuth to 333 degrees azimuth (Plate 12). The colour balance of the original image was retained, but the generalized geometry of the illumination model reduced the high-frequency component of the landscape to such a degree that the image appears blurred.

Plate 11. Value image generated from bands 1, 2 and 3 and processed using intensity conversions calculated from the illumination model.

Plate 12. Colour composite of direct manipulation scene, recombined from processed chromaticity and value components.

Manipulation using LUT inversion

The blurring effect prevalent in the image processed with the direct manipulation method can be eliminated by using only the intensity information inherent in the scene. The topographic lighting effect could be reversed by simply inverting the scene, however inversion of the original RGB composite would result in a colour negative in which colours are represented by their complements which hinders scene recognition (von Gaza, 1989). Inversion can be accomplished independently from the colour component by utilising the intensity component that has been isolated from the chromaticity (Plate 13). The inversion process altered the relative intensity of different cover types and changed the appearance of the surface colour when reconverted back into RGB colour-space (Plate 14). The change in appearance was caused by intensity differences due to albedo variation between cover types being transposed as well as the topographic lighting effect. The relative brightness of colours within the image that is independent of shadow and the topographic lighting effect is referred to as 'the colour balance'. Vegetated areas that were dark due to the absorption of visible light became relatively bright. Rock regions that reflected a large amount of visible light were darkened, while snow, which reflects nearly all incident radiation became black. Although individual cover types cannot be easily isolated and manipulated separately, anomalous areas of saturated snow cover were thresholded and the DN of these regions increased to levels that blended with the surrounding topography. The

Plate 13. Inverted value image with snow areas thresholded to blend in with surrounding cover (DN=0 set to 100).

Plate 14. Colour composite of LUT inversion scene, recombined from processed chromaticity and value components.

resulting image retains a rugged appearance with good definition, however the brightness shift caused by the inversion process altered the colour balance.

High-Frequency Filtering

In order to retain the rugged appearance of the landscape and avoid altering the colour balance, high-frequency intensity differences should be retained, while only the low-frequency portion of the topographic lighting effect must be inverted. A 9x9 boxcar averaging filter removed any variation that occurred within a 9x9 neighbourhood (Plate 15). Subtracting this low frequency value from the original image DN resulted in only high-frequency information being retained (Plate 16). Lighting differences caused by shadows in rugged terrain, textural information, and cover type boundaries are the high-frequency components of intensity that were retained. Medium -frequency components of the intensity image such as cover type albedo differences were too low to be included. The high-frequency lighting differences due to shadow caused perceptual difficulties in the processed image because they gave the appearance of shadowed regions on illuminated slope facets. By inverting the high frequency image (Plate 17) the lighting differences caused by shadow were reversed along with textural and border information. The image was added to an illumination model with the lighting source situated in the north-west (Plate 18), rescaled, and recombined with the chromaticity components to form a colour composite

Plate 15. Value image processed with a 9x9 averaging boxcar filter.

Plate 16. High-Frequency residual image from the subtraction of the averaged value image from the unprocessed value image.

Plate 17. Inverted high-frequency residual image from the subtraction of the averaged value image from the unprocessed value image.

Plate 18. Inverted high-frequency residual image added to an illumination model.

Plate 19. Colour composite of high-frequency addition scene, recombined from processed chromaticity and value components.

(Plate 19). The image contains a relatively neutral colour balance because intensity variation due to cover type albedo has been removed. High frequency information added to the illumination model highlights the texture of the landscape, but lacks the medium-frequency topographic expression that helps define the rugged characteristics of the terrain.

Medium and High-Frequency Filtering

The ideal filter would remove and enable the inversion of only the topographic lighting effect, while retaining the brightness variation associated with different the cover types and textural information. The illumination model, when grey-scaled (Plate 4), represents the incident radiation coming from the light source while ignoring topographic obstructions that cause shadows. This model is generalized due to the small scale of the original map (1:250,000 with 500 foot contours), the smoothing effect caused by the differential geometry calculations (Eyton, 1988), and the boxcar smoothing of the DEM to remove noise. When the orientation of the illumination source is chosen to coincide with the location of the sun in the satellite images a low-frequency generalization of the topographic lighting effect is produced. The subtraction of the illumination model from the original intensity image acted as a filter that removed much of the topographic lighting effect, while retaining medium and high frequency information associated with the various cover types and terrain ruggedness (Plate 20). Since only the general

Plate 20. Medium-frequency residual image from the subtraction of the illumination model (light azimuth=153°) from the unprocessed value image.

topographic lighting effect was subtracted, some topographic information remained as brightness variations for small features in the rugged terrain. The filtered image was then added to the illumination model calculated for a light source located in the northwest (Plate 21). Recombination of the pre-processed hue and saturation images results in an image that retains the colour balance of the original scene while maintaining the rugged characteristics of the terrain and moving the apparent direction of illumination to the northwest (Plate 22).

Inversion of the medium and high-frequency components also caused the small brightness variations within the scene to be inverted (Plate 23, Plate 24). Although this ensures that any remaining topographic lighting effect is also inverted, a slight colour imbalance results due to intensity variation from cover type differences contained in the image (Plate 25). This imbalance was not as pronounced as in the intensity inversion model due the mitigating effects of the illumination model.

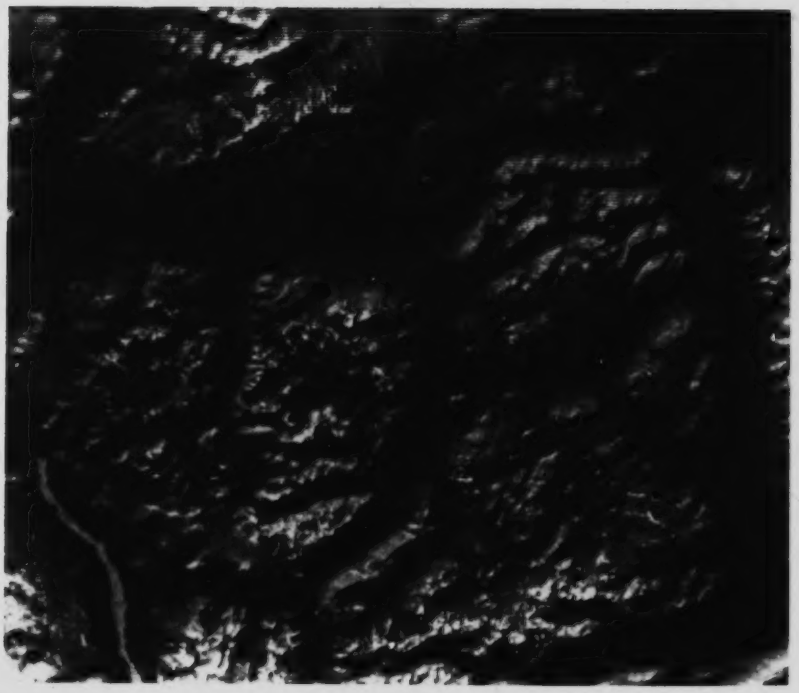


Plate 21. Medium-frequency residual image added to an illumination model (light azimuth=333°).

Plate 22. Colour composite of medium and high-frequency addition scene, recombined from processed chromaticity and value components.

Plate 23. Inverted medium and high-frequency residual image from the subtraction of the illumination model from the unprocessed value image.

Plate 24. Inverted medium and high-frequency residual image added to an illumination model.

Plate 25. Colour composite of inverted medium and high-frequency addition scene, recombined from processed chromaticity and value components.

V SUMMARY AND CONCLUSIONS

In any cartographic representation of the landscape, the primary purpose is to convey the desired information as completely and accurately as possible. The objective of this research was to re-orient the apparent direction of illumination within a Thematic Mapper scene of rugged terrain in which portions of the landscape were obscured by shadow. Additionally, it was desirable to retain the colour balance, surficial texture, and cover type variation, while presenting shadowed areas as visually natural as possible considering the limited available information content within shadows.

In a monoscopic image the low-frequency component of the topographic lighting effect contains the primary key to representing relief. The r^2 value between the illumination model generated from the generalized DEM and the value image was only .32, however when the model was subtracted from the value image essentially no relief was apparent in the resulting image (Plate 20). The illumination model calculated from the generalized DEM approximated the low-frequency component of the topographic lighting effect. Although in rugged terrain there are higher-frequency components of the value image that exist, it is the low-frequency component that is used by the brain to ascertain the topological orientation of the landscape.

The higher frequency components of intensity are indispensable to interpretation of the context and the ruggedness of the landscape. The

medium-frequency content of the topographic lighting effect and shadows caused by high-frequency undulation of the terrain are essential for the perception of ruggedness. Removal of these elements cause the final image derived using the direct manipulation technique to appear blurred and indistinct (Plate 12).

Intensity variation due to differences in cover type albedo and within-cover type albedo are needed to maintain the colour balance within the scene. The colour balance is an important cue that is used to perceive cover type. Modifying the relative intensity between cover types made temperate vegetation in the valleys appear semi-arid when the intensity level of the vegetation was transposed relative to rock surface (Plate 14). Removal of the medium-frequency intensity component resulted in a neutral colour balance that also hindered interpretation of the covertype (Plate 19).

The fourth method was the most successful because it removed and inverted only the low-frequency component of the topographic lighting effect (the key to relief perception). The medium and high-frequency intensity components were retained as a residual image and added to an artificial topographic lighting effect. The resulting final product (Plate 22) shifted the light source to the northwest without altering higher intensity components that are essential to terrain interpretation. Although the fourth method was the most successful when combined with a generalized DEM, the direct manipulation method would work if a suitably detailed DEM was available. The

intensity inversion technique although hindering cover type recognition required no ancillary data and provided a pronounced relief.

The perception of relief is the result of the unconscious assimilation of shading, spectral response, and spatial context within a scene. Most maps are designed to be read with north on the upper border and people generally find images easier to interpret when they are aligned in a similar fashion. The relocation of the illumination source to a position above the visual horizon utilizes an inherent visual characteristic of the human visual system to complement learned spatial recognition. The orientation of the image and the cues within the image enhance the ability for individuals to understand and interpret the topological context of the landscape. This research has also facilitated a recognition of the complex nature of how humans interpret three dimensions and learn to recognize spatial topology.

REFERENCES

ANGELL, I. O. and GRIFFITH, G., 1987, *High-resolution Computer Graphics Using FORTRAN 77*, London: MacMillan Education.

CIVCO, D. L., 1989, Topographic Normalization of landsat thematic mapper digital imagery. *Photogramm. Engng. Remote Sensing*, **9**, 1303.

COYOTE, W. E., 1964, *Techniques for mapping of road runner habitat (Speedibus speedibus goodibus eatibus)*, Flagstaff, Ariz.: ACME publishing corp.

CROOKS, L. K., 1989, *Digital Mapping Techniques to Determine Dall's Sheep Winter Habitat in the Yukon Territory*, Unpublished Masters Thesis, University of Alberta.

DONKER, N.H.W. and MEIJERINK, A.M.J., 1977, Digital processing of LANDSAT imagery to produce a maximum impression of terrain ruggedness, *ITC Journal*, **4**, 683-702.

EYTON, J. R., 1988, Mapping the differential geometry of digital elevation models; *in press*, Department of Geography, University of Alberta, Edmonton, Alberta.

GILLESPIE, A. R., KAHLE, A. B., WALKER, R. E., 1986, Color enhancement of highly correlated images. I. decorrelation and HSI contrast stretch, **20**, 209-235.

GILMAN, C. R., 1981, Manual/photomechanical relief shading, *American Cartographer*, 8, **1**, 41-53.

GONZALEZ, R. C., and WINTZ P., 1986, *Digital Image Processing*, Reading, Mass.:Addison-Wesley Publishing Company, Inc.

GREEN, W. B., 1983, *Digital Image Processing*, New York, N.Y.: Van Nostrand Reinhold Company, Inc.

HALL-KONYVES, K., 1987, The topographic effect on LANDSAT data in gently undulating terrain in southern Sweden, *Int. J. Remote Sensing*, 8, **2**, 157-168.

HEARN, D. and BAKER, M. P., 1986, *Computer Graphics*, New Jersey: Prentice Hall, Inc.

HOLBEN, B., and JUSTICE, C. O., 1980, The topographic effect on spectral response from nadir pointing sensors. *Photogramm. Engng. Remote Sensing*, **9**, 1191.

HOLBEN, B., and JUSTICE, C. O., 1981, An examination of spectral band ratioing to reduce the topographic effect on remotely sensed data. *Int. J. Remote Sensing*, **2**, 115.

HORN, B. K. P., 1982, Hillshading and the reflectance map. *Geo-Processing*, **2**, 64.

JUSTICE, C. O., WHARTON, S. W., and HOLBEN, B., 1981, Application of digital terrain data to quantify and reduce the topographic effect on Landsat data. *Int. J. Remote Sensing*, **3**, 213.

KIMES, D. S. and KIRCHNER, J. A., 1981, Modelling the effects of various radiant transfers in mountainous terrain on sensor response. *IEEE Transactions on Geoscience and Remote Sensing*, GE-19, **2**, 100-107.

KOWALIK, W. S., LYON, R. J. P., SWITZER, P., 1983, The Effects of Additive Radiance Terms on Ratios of Landsat Data. *Photogramm. Engng. Remote Sensing*, **5**, 659-669.

KOWALIK, W. S., MARSH, S. E., LYON, R. J. P., 1982, A relationship between LANDSAT digital numbers, surface reflectance, and the cosine of the solar zenith angle. *Remote Sensing of Environment*, **12**, 39-55.

LILLESAND, T. M. and KIEFER, R. W., 1987, *Remote Sensing and Image Processing*, New York, N.Y.: John Wiley and Sons, Inc.

PAVLIDIS, T. O., 1982, *Algorithms for Graphics and Image Processing*, Rockville, Md.: Computer Science Press, Inc.

RAMACHANDRAN, V. S., 1988, Perceiving shape from shading, *Scientific American*, 259, **2**, 76-83.

RICHARDS, J. A., 1986, *Remote Sensing Digital Image Analysis*, Berlin: Springer-Verlag.

ROGERS, D. F., 1985, *Procedural Elements for Computer Graphics*, New York, N.Y.: McGraw Hill.

SMITH, A. R., 1978, Color gamut transform pairs, *Computer Graphics*, **12**, 3, 12-19.

SMITH, J. A., LIN, T. L., RANSON, K. J., 1980, The Lambertian Assumption and Landsat Data, *Photogramm. Engng. Remote Sensing*, **9**, 1183-1189.

TEILLET, P. M., GUINDON, B., GOODENOUGH, D. G., 1982, On the slope-aspect correction of multispectral scanner data, *Can. J. Remote Sensing*, 8, **2**, 84-106.

VON GAZA, P., 1989, *Image Enhancements for Mineral Exploration*, Unpublished Masters Thesis, University of Alberta.